

Methodology for Analysis and Simulation of Large Multidisciplinary Problems

by

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I. Introduction

The Integrated Structural Modeling (ISM) program is being developed for the Air Force Weapons Laboratory and will be available for Air Force work. Its goal is to provide a design, analysis, and simulation tool intended primarily for directed energy weapons (DEW), kinetic energy weapons (KEW), and surveillance applications. The code is designed to run on DEC (VMS and UNIX), IRIS, Alliant, and Cray hosts. Several technical disciplines are included in ISM, namely structures, controls, optics, thermal, and dynamics. Four topics from the broad ISM goal will be discussed in this paper. The first is project configuration management and includes two major areas: the software and database arrangement and the system model control. The second is interdisciplinary data transfer and refers to exchange of data between various disciplines such as structures and thermal. Third is a discussion of the integration of component models into one system model, i.e. multiple discipline model synthesis. Last is a presentation of work on a distributed processing computing environment.

II. Overview of ISM

An overview of the ISM architecture is described to provide a framework for the various subjects that will be covered. Figure 1 shows the general organization of the system. The ISM user accesses the system capabilities through the ACE (Analysis Capability Executive) executive program. The executive provides a graphical menu interface and a command language interface which can operate in either an interactive or batch mode. It allows running of other modules such as NASTRAN and SINDA (Systems Improved Numerical Differencing Analyzer), detailed manipulation and query of data, and interfacing with the database and host operating system. Operational features include command procedures, macros, journaling, and variable computations with looping and branching.

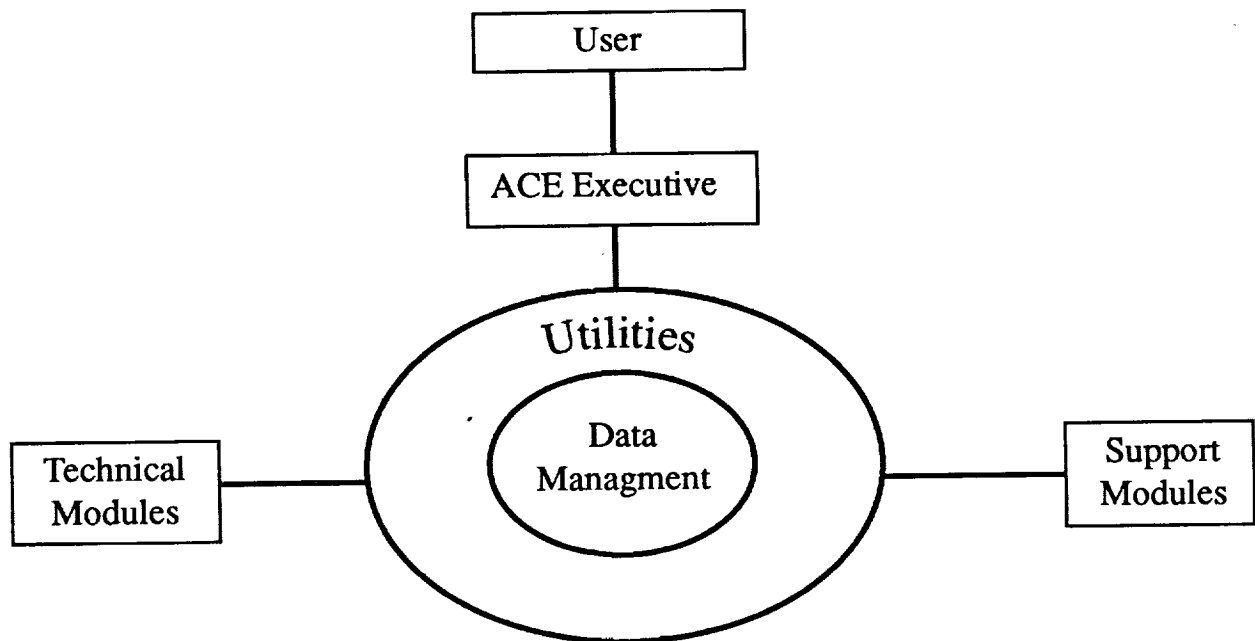


Figure 1. ISM Architecture

The ISM utilities support application programs as well as the executive. The utilities provide a toolkit for managing the database, performing file transfers, setting up and accessing a dynamic memory workspace, and handling system parameters and messages.

The system data storage includes three parts: a multi-user database, with formal cataloging and retrieval capabilities; a temporary workspace, specific to each user or application program; and the host file system. Data may be stored in a general ISM defined table form, as arrays (matrices with labels), or in more arbitrary data structures defined by users or application programs.

Technical modules address the structures, controls, optics, thermal, and system dynamics disciplines. Support modules provide graphics and pre/post processing, interfaces between technical modules, and data flow with CAD and other external databases.

III. Project Configuration Management

On large multidiscipline problems, management of software, database, and models becomes critical to the flow of a project. Multidiscipline software packages often begin as a set of stand alone modules with ad hoc data organization/ management and user interfaces. As the number of modules and supported solution paths increases, common executive program and database features become increasingly important to both the software developers and the users.

Because the number of module interfaces can approach an n^2 relationship as shown in figure 2, costs for expansion of a poorly managed system can become prohibitive. The solution to this problem is to develop a common executive and database. With this organization, only one interface between the executive and each module needs to be created. Both multidiscipline users and single discipline specialists on multidiscipline teams, benefit from standard data structures, advanced data handling tools and a consistent top-level user interface. The benefits include less costly learning/relearning curves, faster data flow, and fewer user/software errors. Both program developers and users benefit from more efficient maintenance and the easier incorporation of new technology.

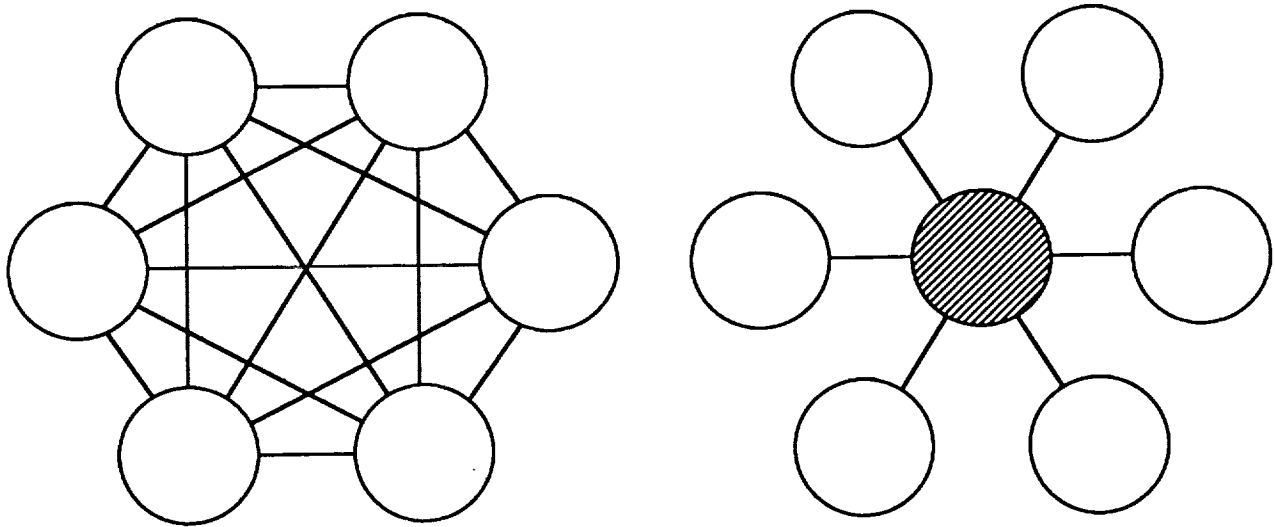


Figure 2. Software/Data Configuration Management

Large aerospace projects are costly and require the close coordination of many groups and disciplines. Participants include program management, design and manufacturing personnel, analysts, and the customer. Much of the configuration management problem arises because several project configurations must be managed.

The current baseline system configuration must be stored in the common database, for access by all. Typically one or two older versions of this baseline also exist. These versions must be accessible for backup and to maintain traceability. The system configuration must be formally controlled by the project chief engineer, and only authorized updates allowed.

Partial configurations and component models are also required for the designers and analysts, and versions of these may either lead or lag the baseline. Each analysis technology (dynamics, controls, thermal, etc.) and design area will require one or more models. For example, the thermal models almost always require different mesh refinement than the structural models, thermal insulation material may be non-structural in nature, etc. The analysis database must support these diverse needs, but still allow required data flow (e.g. thermal loads on the structural model to compute thermal deformations).

Configuration management requirements include data cataloging and query/retrieval, version control, database interfaces to project subgroups and to the outside world, and compatibility with the major project hardware, and software components.

IV. Interdisciplinary Data Transfer

Data is often passed between various disciplines. For example, results from a normal modes analysis may be passed to a controls or multibody code. In order to pass the data, ISM transfers the information to a common database where it can be accessed by other modules. The database is a logical environment for configuration management. In addition any number of modules can gain simultaneous access to the current system baseline or developmental versions. There are generic data manipulation tools that provide an extra dimension of flexibility (in addition to the discipline specific modules).

To illustrate some conventional paths, consider an optical beam analysis where a finite element structural model of the mirrors and associated structure is constructed in NASTRAN (or ANSYS). The system mass, stiffness, damping, node locations, generalized matrices, etc. can be stored in the ISM database. Optical sensitivity coefficients that relate structural displacements to beam direction are calculated and stored in the database. Sensor and actuator models are defined and stored. All or some of this data is combined for control design. Once the controller is designed a high fidelity simulation can be conducted using all the component models. Finally, detailed performance evaluation is done via simulation data post processing and wavefront propagation analysis. Each part of the system can be modeled several times with varying degrees of sophistication. See figure 3.

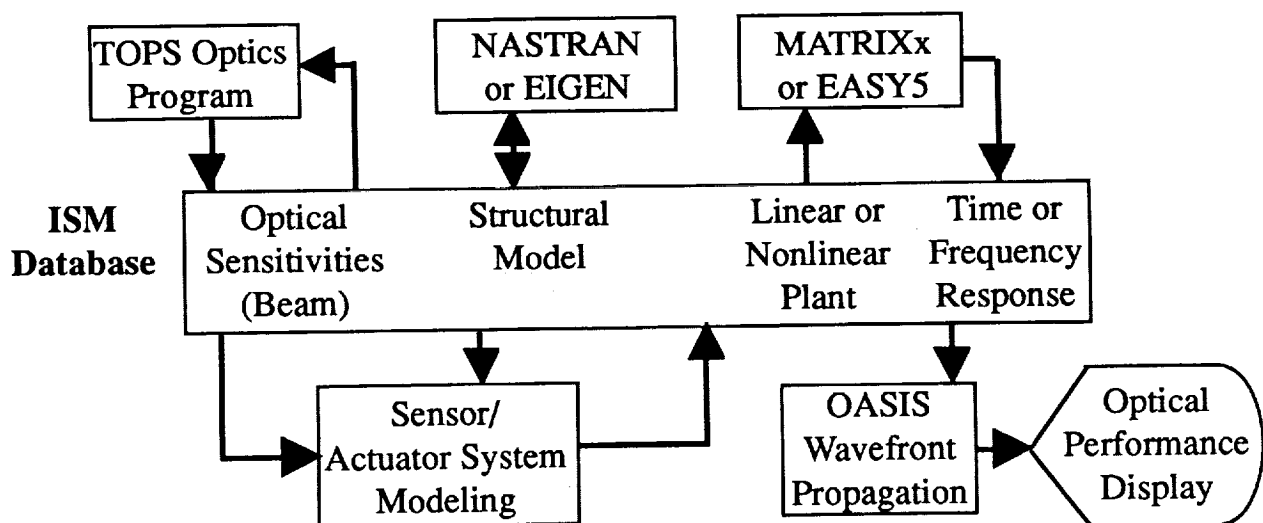


Figure 3. Simple Integrated Modeling Blocks

Several examples of interdisciplinary data transfer are given. The first is the LEAP (Lightweight Exoatmospheric Projectile) ISM demonstration exercise. Results from dynamics and optics analysis are combined with disturbance data to predict line of sight jitter. Two structural models were converted from ANSYS and SAP into a combined NASTRAN dynamics model (11,000 DOF). The ISM EIGEN module was used to find the modes and frequencies using the NASTRAN generated nodal mass and stiffness matrices.

The ISM TOPS module was used to derive sensitivity coefficients. Once these tasks were completed ORACLS used the optical sensitivity matrix and the modes and frequencies of the structure to create a state space model which formed the basis for the system simulation in MATRIX_x. See figure 4.

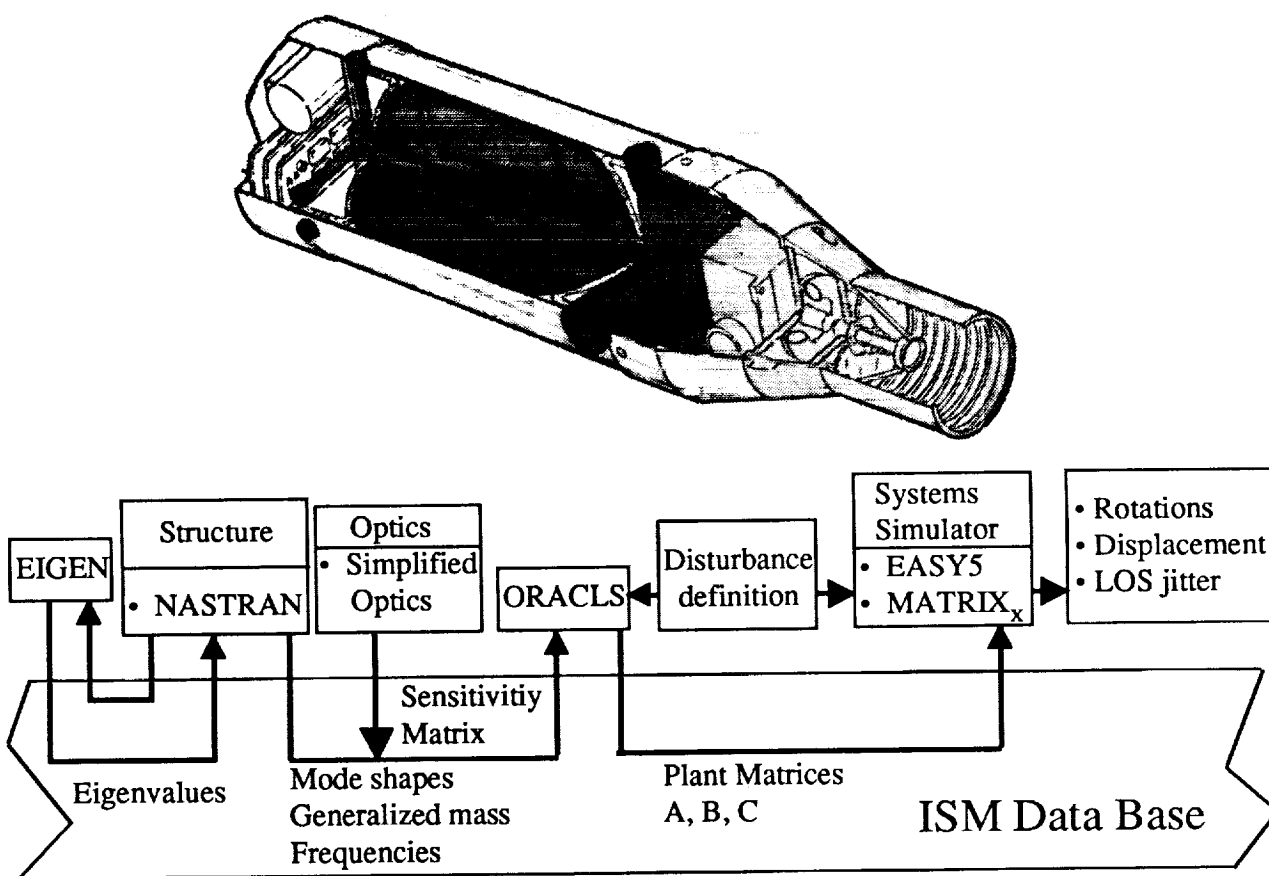


Figure 4. LEAP Interdisciplinary Data Transfer

Another example where interdisciplinary data transfer was used was in support of the design of the ASTREX (Advanced Space Structures Technology Research Experiments) test facility for the Air Force Astrodynamics Laboratory. The application involved a substructure merge of an air bearing pedestal, a test article, and an air cushion. The structural model was rooted and the modes and frequencies were used with the optical sensitivity coefficients obtained from TOPS, to conduct closed loop simulations in EASY5, a controls code. As in the LEAP analysis, data from structures, optics, and controls was

combined in the final simulation. The ISM database minimized the burden on the analyst during the transfer of data. See figure 5.

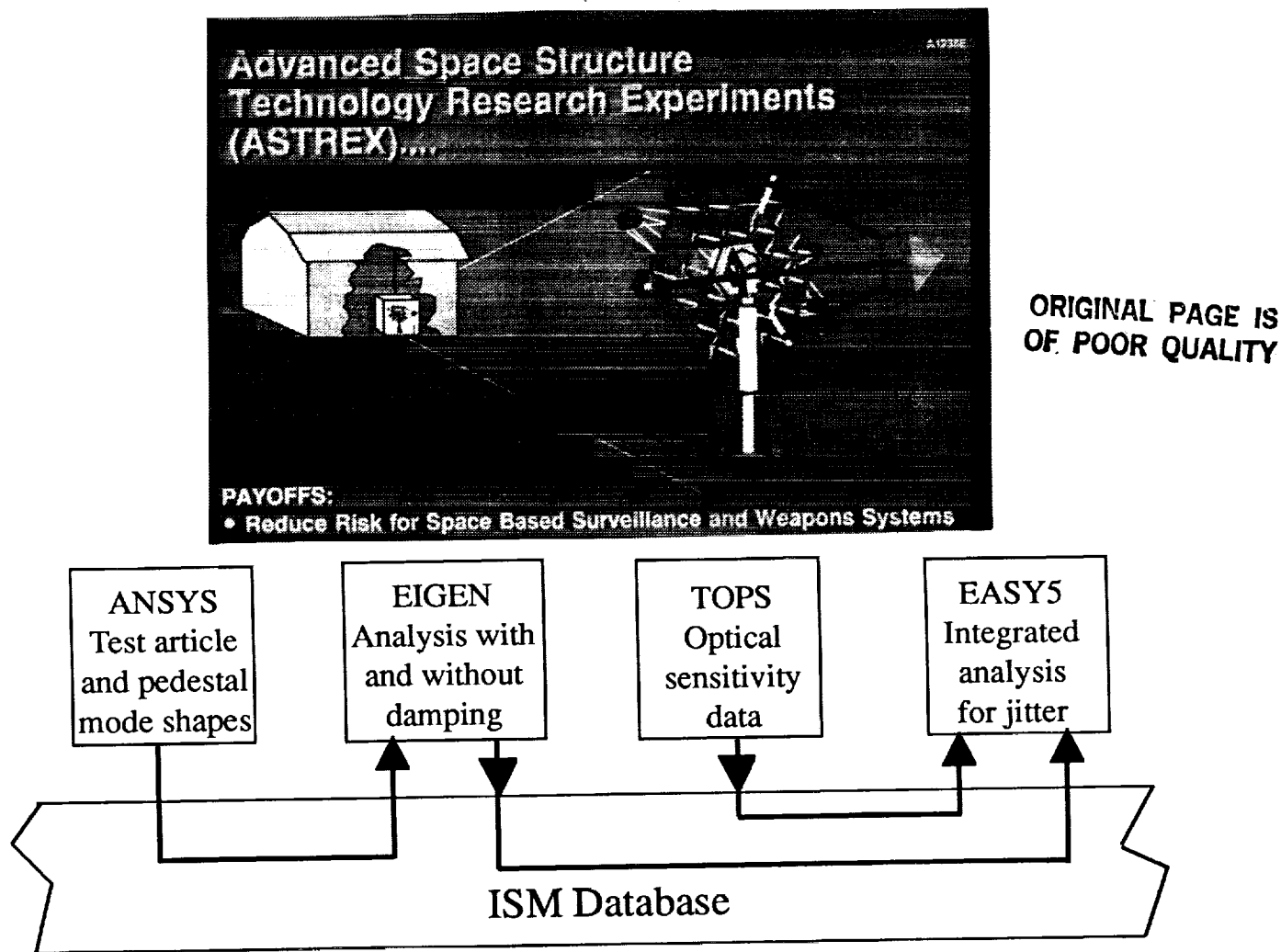


Figure 5. ASTREX Demonstation Analysis

The final example involves the Carbon-Carbon Wingbox analysis that combined data from a thermal analysis with a structural model. SINDA was used to perform the thermal analysis. The radiation exchange factors within the wingbox were calculated using the program TRASYS (Thermal Radiation Analysis System). The stresses were determined using ANSYS. Two separate meshes were created for the wingbox. One mesh was the finite element mesh for ANSYS, and the other was a finite element mesh that was then converted into a finite difference model for SINDA. The results from the thermal analysis were stored in the database. Using the module MIMIC (Model Integration via Mesh Interpolation Coefficients), the temperatures in the thermal model were interpolated to the nodes of the stress model. ISM commands were then used to write the data out to a file in a suitable format for ANSYS. See figure 6.

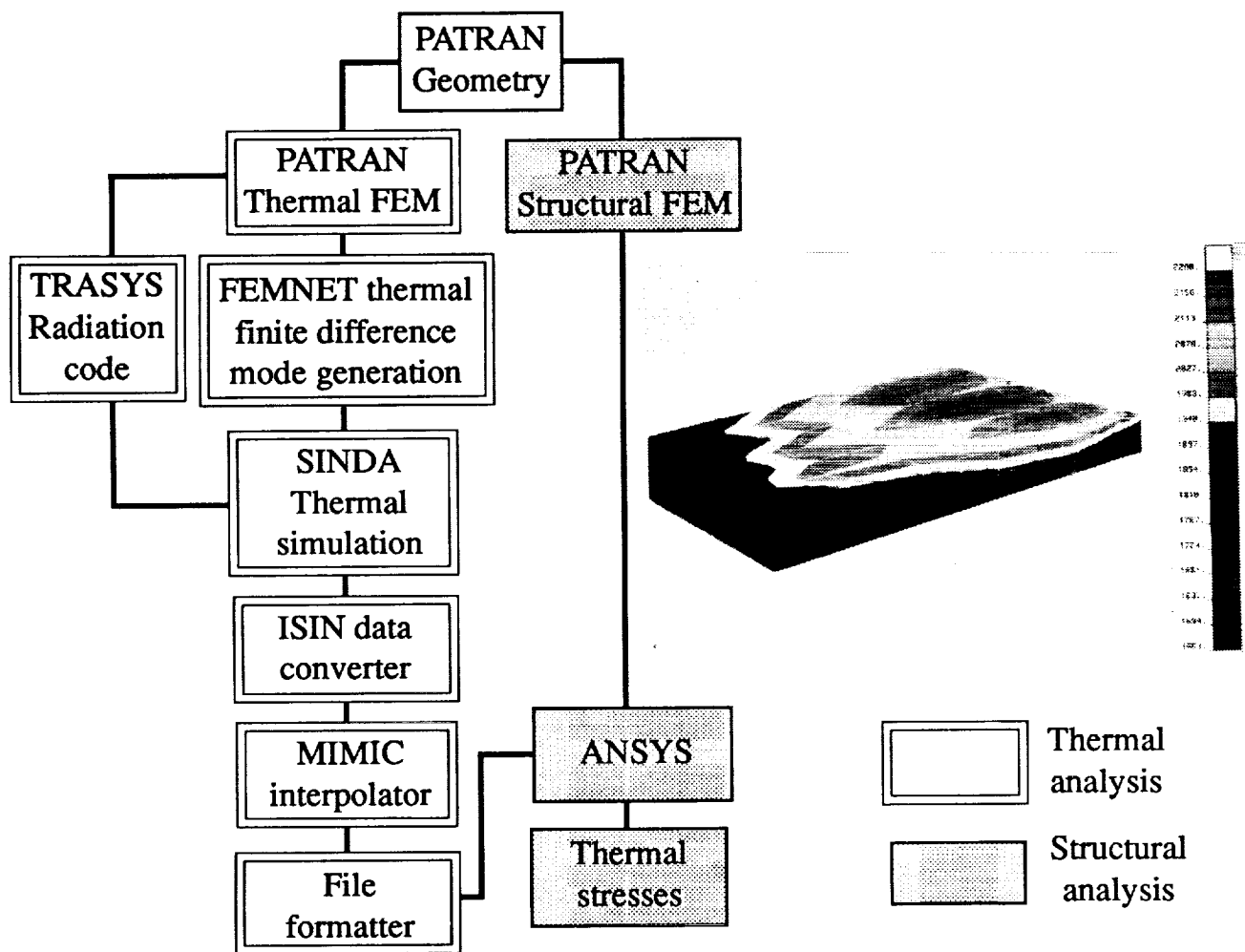


Figure 6. Carbon-Carbon Wingbox Analysis

V. Multiple Discipline Model Synthesis

The ability to transfer data between disciplines allows the formulation of multiple discipline models. Before considering multiple disciplines, note that the need for synthesizing models from incompatible software packages is common in multiple company contracts. The LEAP project is an example of combining models from two different organizations and two different software packages (an ANSYS model with a SAP model). The larger the model the greater the difficulty associated with the translation due to unique features found in each package. Controls, a discipline in itself, already performs simulations to predict system response. Many times these simulations are reasonable in size and are easily handled by one person. Typically a structural model within a simulation consists of a reduced model (a set of mode shapes). The assumption is that these mode shapes characterize the solution space of the system. However, when the control loop is closed, the system mode shapes change. In many cases

the reduced set of mode shapes from the open loop system is not sufficient to characterize the mode shapes for the closed loop system. In this case it would be appropriate to combine the controls and structures models before reducing the model. The resulting closed loop basis can improve the accuracy in ensuing analysis.

An example of the errors that can be associated with an open loop basis is shown. The size of the structural model mandates the use of a reduced basis in most problems. The use of an inadequate basis will result in significant error. This is demonstrated with a passive damping problem and is analogous to the errors that can occur in a rate feedback problem. The graphs show the percent difference from the exact complex Lanczos solution, for the several approximate solution methods shown. The points that vary the most from the Lanczos solution are calculated using the Strain Energy Method. A slightly better solution is found using a Rayleigh proportional approximation. The next four solutions are performed using a reduced basis. The lowest modes for an undamped system are used as an approximate solution (a basis) to solve the damped problem. This is analogous to using open loop structural modes as a basis for a closed loop active system. In solutions using a reduced basis, 30, 60, 120, and 240 modes are used as the reduced basis. Increasing the number of modes improves the accuracy of the solution, but predictions of the performance (modal damping) based on a reduced set of modes result in large error. See figure 7.

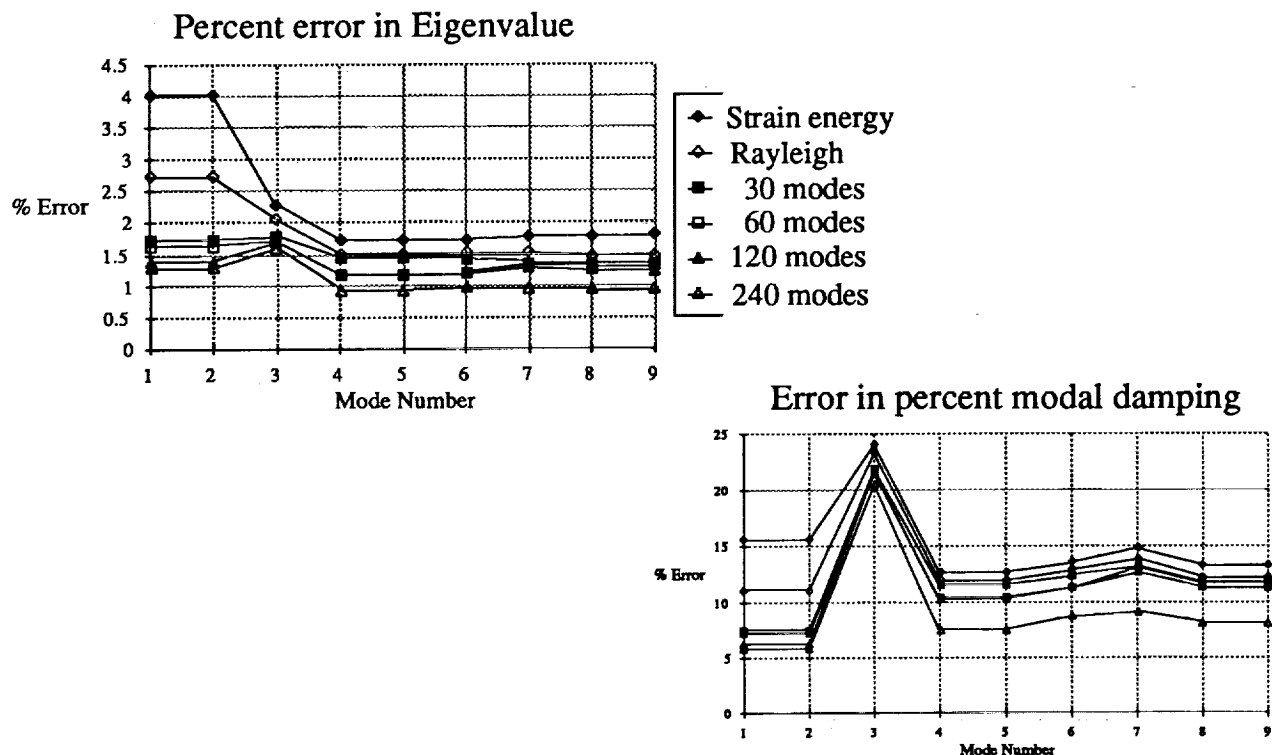


Figure 7. Error In The Use Of An Open Loop Basis

V. Distributed Processing

A distributed processor computing environment is key to productive large multidiscipline simulations. The primary use of distributed processing will be to allow the ISM user to function within a workstation environment while processing data on the "optimum" computers. The use of the term optimum may simply refer to the computer on which a particular piece of software is hosted or may refer to the one with the most unused time.

A secondary yet powerful use of distributed processing is to spread the computational burden of a multiple discipline ISM simulation over several available processors. The simulation must be distributed in a rational manner. There are two key factors involved. It is important to minimize the communication between the processors. It is also important to balance the computational efforts required by each component with the capabilities of the processors at hand. See figure 8.

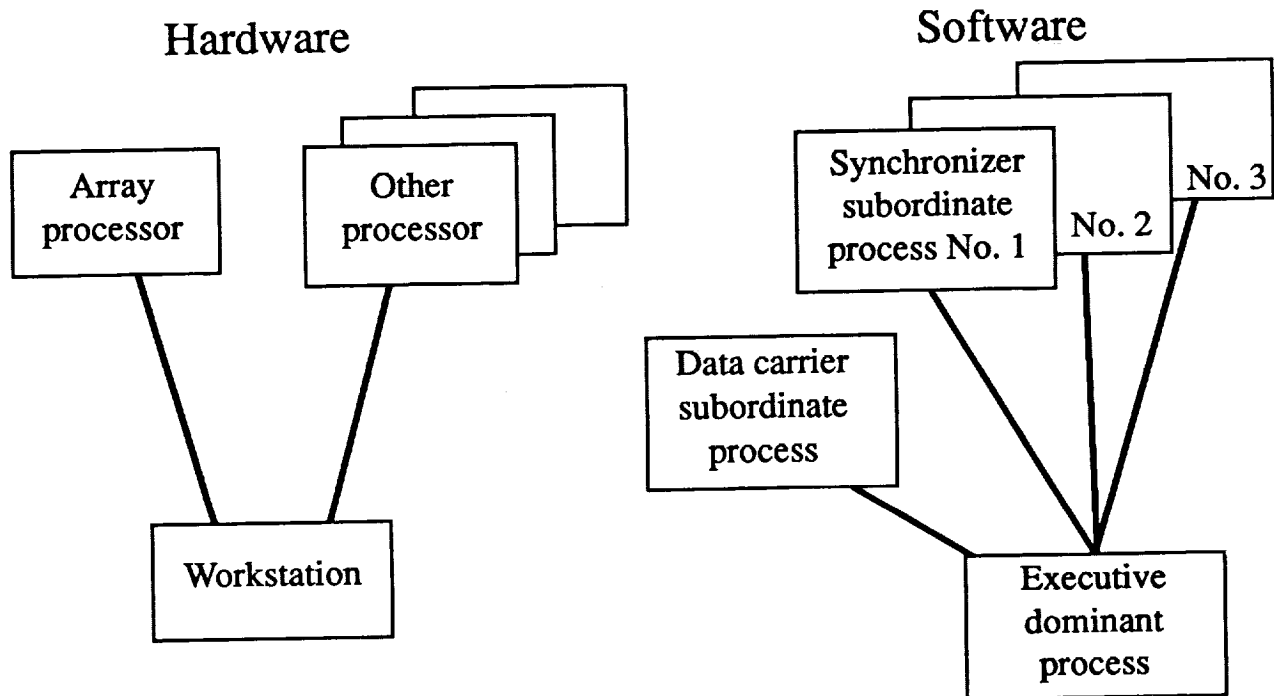


Figure 8. Network Computing System

A third capability that distributing processing allows is real time processing. ISM has not been designed with this in mind; however the tools to do this kind of work will be in place.

Distributed processing software enables the user to distribute the processing of a single application to several computers and maintain copies of data on several interconnected networks.

A demonstration of distributed processing has been completed.

VI. Summary

ISM is under development and is actively being used to support current multiple discipline simulations. Among the tools that are developed are those for controlling the project models and analysis. These include a database where key models and information can be stored and a protection scheme to limit the access and ability to change the database. In addition, utilities and interfaces exist to transfer data between various analysis modules (for example, between thermal analysis and structural analysis, or between optics and controls). These tools will facilitate the multidiscipline analysis that can be used to analyze large COSI (control, optics, structure interaction) problems. Distributed processing is utilized to make better use of computer facilities.